Training Effectiveness of Embedded Training in a (Multi-) Fighter Environment

A Discussion Paper

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ABSTRACT

By feeding simulated threats into the available sensor channels of the fighter aircraft in-flight, the threat appears lifelike to the pilot. This allows tactical training against a virtual force, or against a real force that can be "virtually augmented": embedded training.

Since the late 1990s, NLR and Dutch Space have cooperated in transforming embedded training from a concept to reality for the F-35 Joint Strike Fighter. Single-ship capability was demonstrated in 2004 on an operational Royal Netherlands Air Force F-16 (see Krijn and Wedzinga, 2004). In 2007, the multi-ship demonstration at Lockheed Martin provided further insight into the technical maturity and the additional advantages of multi-ship embedded training. Using multi-ship embedded training, fighter pilots can train in-flight within one shared tactical environment. To implement this capability, each aircraft is fitted with a computer system with embedded training software. The software uses an existing data-link to ensure each aircraft has the same tactical picture. Early 2009, Dutch Space and NLR received the go-ahead from Lockheed Martin to further develop embedded training for the F-35 Joint Strike Fighter.

Analysis has shown 30% increase of training effectiveness at the same cost when using embedded training (estimates concerning RNLAF for F-16 Continuation Training) (Stokkel and Wegkamp, 2006).

However, implementation of an embedded training capability, as foreseen for the Block-3 version for the F-35 Joint Strike Fighter is probably only the beginning of an excitingly new training paradigm. Little research has yet been devoted to the analysis of training objectives to which it could contribute, given the full range of operational tasks of the user organization. In addition to fitting embedded training to the training objectives, the training practices and processes within the user organisation should be reviewed. After all, careful adaption of existing training practices is crucial for successful embedding within the armed forces.

In this paper, we explore how embedded training relates to user needs and how embedded training could best contribute to the fulfilment of the training objectives for fighter pilots. Further, my aim is to sketch a qualitative identification of the training effectiveness of embedded training when compared with "legacy" live training exercises or tactical training on simulators. Finally, the integration of embedded training with other forms or Live-Virtual -Constructive training is looked at.

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1.0 INTRODUCTION: WHAT IS EMBEDDED TRAINING FOR FIGHTER AIRCRAFT?

By feeding simulated threats into the available sensor channels of the fighter aircraft in-flight, the threat appears lifelike to the pilot, which allows tactical training against a virtual force, or against a real force that can be "virtually augmented". This technology on-board the aircraft is called Embedded Virtual Simulation (EVS), and it enables Embedded Training (ET).

ET can be supported with playback and debrief capability on the ground. A current evolution in ET is that it will be possible to receive and transmit threat information via data-link between the EVS-equipped aircraft in a formation, such that a common tactical picture can be provided to all members of the formation, which enables multi-ship ET. In a more advanced form it would be possible to influence the tactical picture (notably, threat behaviour) by data-link from a "scenario management" or instructor position, e.g. on the ground. From there, the step in which ET equipped aircraft can participate in Live-Virtual-Constructive (LVC) training scenarios seems to be a tangible one. Live-Virtual-Constructive (LVC) training combines training applications falling under the three discrete categories:

- live training, on actual platform hardware;
- virtual training, on manned simulation;
- constructive training, with computer generated battlefield conditions.

In fact, by this definition, ET is already a form of LVC training, since it combines live training on actual fighter aircraft with a manned simulation of components of the own-ship and on-board computer generated threats that represent battle-field conditions. This combination of training applications makes ET a "light" and easy to organise form of LVC-training, which is enabled by the EVS on-board the aircraft, which is essentially a software-module that interfaces with the aircrafts' mission system via the aircraft's data-bus.

2.0 WHAT CAN ET DO FOR THE USER?

ET for fighter aircraft addresses user requirements at multiple levels. At the National level, ET would increase the efficiency of training with reduced environmental impact and would increase the combat readiness of the force. The latter advantage is not to be underestimated in an era of shrinking defence budgets and an increasing Ops Tempo, with out-of-area deployments and reduced opportunity for training in the homeland. At the level of the Air Operations Centre, ET would enable realistic air campaign planning and would provide a means to validate the Command and Control chain under realistic conditions. At the squadron level, ET enables training of the full sortie-generation cycle, on a day-to-day basis. ET eliminates the need of mimicking adversary weapon platforms, and eliminates the high costs for equipment, logistics, planning and personnel imposed by the use of instrumented ranges. Finally, at the level of the end-users, i.e. the flight crew, a high-fidelity tactical training and rehearsal environment is provided. This includes an enlarged training range, Surface-to-Air Missiles (SAM) training anywhere, any time, secure low-cost readily available Electronic Warfare (EW) training, realistic emissions of ground threats and the possibility to train several scenarios in one sortie. At the same time, this would minimize the need for flights acting in the role of opposing force. All these factors would significantly increase the effectiveness of flight hours for the participating pilots.

However, when considering EVS as a training medium, it is legitimate to pose questions like:

- Which tasks can be trained with ET and how would that affect the learning-curve of pilots and others involved in the sortie generation process?

- What transfer-of-training can we expect when the pilots are exposed to actual battlefield conditions, rather than the simulated battlefield used in ET, and are there elements in the ET system that carry the risk of negative training?

- What are the current limitations of ET, e.g., thinking of real-life scenarios in which adversaries might come into visual range, visual effects of weapon fly-out and battle damage assessment and truly intelligent adversaries?

3.0 WHAT ARE THE MAIN COMPONENTS OF THE EVS SYSTEM?

An EVS system, carried on-board of aircraft, consists of three main simulation modules (see figure 1):

- First, the simulation management module performs many functions, such as starting and stopping training exercises and taking care that all players participating in the exercise have synchronised information.

- Second, the own ship simulation module stimulates the on-board sensors and simulates the own weapons and electronic warfare systems.

- Third, the virtual world simulation simulates the virtual players (Computer Generated Forces, CGF's) in the exercise. The virtual world simulation also comprises models for the terrain over which the exercise takes place and atmospheric conditions.

In either case, the design requirements for the ET simulation modules should be a direct function of the training needs, and consequently, essential for the fulfilment of the training objectives.
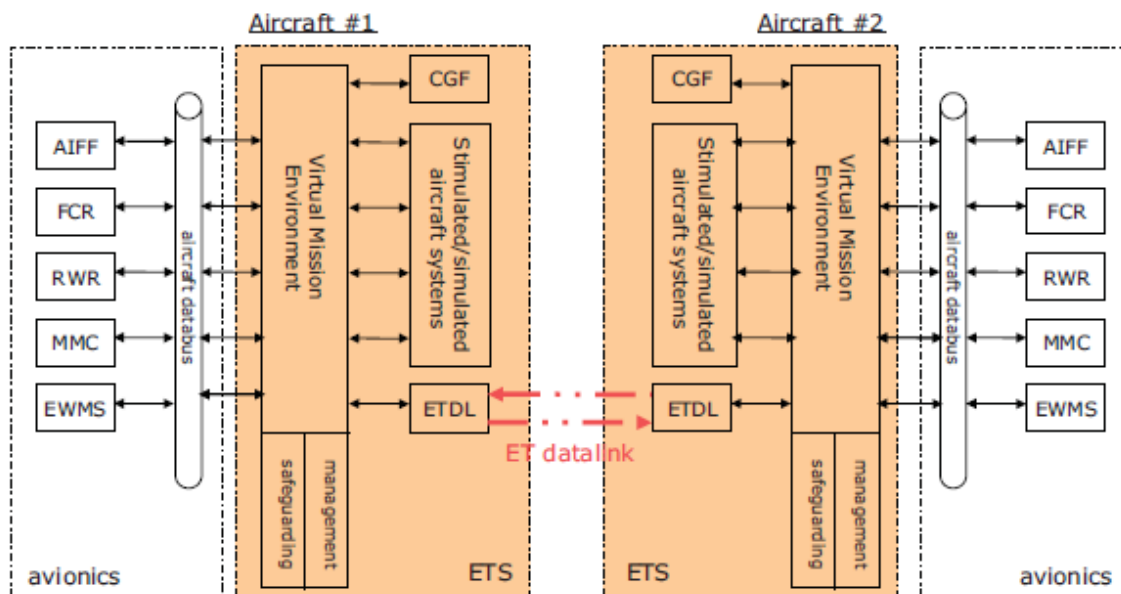

Figure 1: multi-ship implementation of EVS, as it was implemented in the demonstration test bed (from Lemmers, 2007)

4.0 INSERTING ET INTO A TRAINING PROGRAM

Fighter pilot training proceeds through several stages of initial training and continuation training. Pilot training starts at the elementary military pilot school, via the combat ready stage to Fighter Weapons Instructor Training and *mission rehearsal* directly preceding the in-theatre sorties.

The decision to include a certain training method in a training program is governed by the expected efficiency and effectiveness of the training method. Transfer-of-training is a central concept to this decision. Pilots confronted with an actual battlefield situation (situation B) will try to apply the solutions or operative procedures that they have already applied in previous situations (situation A). When performance in situation B is made easier after training in situation A, transfer is said to be *positive*. Transfer of A to B could also be *negative* when the effects on the pilot's performance in situation B are negative. In addition, transfer effect can be null when the training situation (A) has no effect on actual battlefield performance (B). For ET, transfer-of-training would depend on the actual capabilities of the EVS, including the perceived realism of the simulated air power, features that would promote instruction, training management and its usability at the squadron and training-organization.

Under the assumption that transfer-of-training of ET is positive, there are additional conditions that determine the position of ET in a training program. Firstly, it depends on the type of platform on which it is implemented. For example, when Embedded Virtual Simulation would be implemented on a trainer aircraft, ET could be used in the early stages of initial training, addressing different training objectives than when implemented on an operational fighter aircraft. In the latter case it could be used in the later stages of initial training and in continuation programs throughout the pilot's career. Secondly, the position of ET in the training program depends on the planned sequence of training activities. This, in turn, depends on such issues as the availability of other training methods and the gamut of available devices, ranging from part-task training via distributed mission training to ranges for live weapons firing.

5.0 POSSIBLE TRAINING TASKS AND TRAINING OBJECTIVES FOR ET

In theory, all operational tasks aboard a fighter aircraft that can be trained in-flight can also be trained with ET. It would go beyond the scope of this paper to specify the competencies that pilots participating in a specific training program are to gain as a result of specific ET exercises. However, ET offers unique opportunities in terms of realistic perception of the battlefield environment while at the same time co-ordinating with other members in the formation. Since Embedded Training (ET) has numerous Beyond-Visual-Range (BVR) benefits, and because wars cannot be contained to the BVR regime -- that is, pilots involved in an air-to-air engagement will eventually enter within visual range of their opponents and/or their weapons -- to preserve the value of ET, the transition to the visual arena needs to be natural and realistic.

However, in the current form, lack of visual display of the simulated entities on the battlefield in ET-enabled aircraft will require additional forms of training, e.g. using augmented role-play or ground-based simulation. Particularly for air-to-ground and close range air-to-air tasks, realistic visualisation of targets may be challenging. This may require high-resolution/ high-contrast display of simulated targets on the see-through visor mounted to the pilot's helmet conformal with the physical environment. This would also rather complicated management techniques for such targets, conformal with head/eye position of the pilot, clouds, mountains, sun rays, and etcetera. Therefore, today, ET in fighters is restricted to scenarios in which the visibility of simulated threats, targets, wing men and other entities by the human eyes is not a critical component of the tasks to be trained. Tasks to be trained would however include most important elements of the kill chain - i.e. the stage target cycle of find-fix-track-target-engage-assess, and the

survivability chain, i.e. preventing of being detected, tracked and/or shot, breaking enemy missile guidance, and eventually surviving after being hit. This could include the following tasks of a typical air-to-air engagement (Roessingh et al, 2003):

(1) In the detection and localisation task, locations of hostiles are communicated by GCI or AWACS via data-link or voice communication, or are obtained by scanning the radar display for possible targets (autonomous detection via radar is common, even with AWACS/GCI present). In the latter case the possible targets need to be in the radar scan volume. It is also possible to detect and localize targets using RWR indications (when under attack), using electro-optical means (infra-red), via adversary's electronic counter measures, or via data-link/ link 16. All pilots in a flight participate in detection and localisation. Flight members will usually concentrate on different, pre-briefed, sectors. When a possible target is detected, the information is shared with all flight members via radio (voice) and/or via data-link (data-link message). Current EVS is restricted to detection with BVR means. Visual detection of simulated hostiles WVR is not yet supported by EVS, unless other flights take-on the role of WVR targets, which would require flights in the adversary role and reduce the advantage of ET. Fighter pilots can however gain importantly by improving the skill to detect targets in the peripheral visual field (Schallhorn and Daill, 1990).

(2) Identification (ID) of intercepted aircraft, a mandatory step prior to weapons employment, is preferably done via electronic means (Electronic Identification, EID) at longer (BVR) ranges, using IFF codes of targets on radar, RWR indications, aircraft emissions, RCS or IR signature. However, if EID fails, Visual Identification (VID) must be done, which is not yet supported by EVS. VID would only be possible when the pilot can clearly see discernible features of the (simulated) target, such as plane shape, number of vertical tails, inlet shape, etc. The range between the two aircraft is typically inside 5 NM, and may be as close as 1-2 NM when similar looking aircraft types are on opposing sides (e.g. Hornet versus Fulcrum). Once target ID is determined, the pilot must further decide if the target is 'hostile', i.e. from the enemy nation, which may also require visual contact. It is clear that these type of visual tasks call for EVS with sophisticated visual modelling and display of targets.

(3) Targeting, i.e. assigning each flight member's radar to a unique enemy group such that the maximum number of enemy targets can be engaged, is a standard procedure, typically dealt with in the flight brief. Flight members target and further divide responsibility for targets (sorting) at a pre-planned range, usually BVR. Multi-ship ET is suited to train targeting and sorting tasks. However, visual sorting may also occur.

(4) The attack phase is heavily intensive, decision times are short and the attack is characterised by a highly dynamic environment and intensive team-co-ordination. The attack task may heavily rely on visual contact with the target, such as (maintaining) target acquisition and manoeuvring. WVR-Manoeuvring is based on visual estimation of the target range, aspect (the angle-off-tail of the target as viewed from the own-ship, which can be primarily determined when features of the target can be distinguished), closure (the relative speed between own-ship and target, which can be primarily determined by the change in visual angle, growth or shrink, of the target) and Line-Of-Sight (the drift of the target across the own-ship canopy). To train a WVR attack-phase would pose a considerable challenge for development of EVS. However, BVR- and other components of the attack phase can be realistically trained with multiship-ET. Examples of these tasks are to maintain situation awareness with the other flight members, monitoring the ownship energy state, weapon selection and (simulated) weapon release. The feel of the aircraft provides an important 'subjective' measure of energy-state. Current EVS is well suited for the latter type of tasks.

6.0 EMBEDDED VIRTUAL SIMULATION AS A TRAINING MEDIUM

For pilot training, EVS is a relative new training medium which must be positioned somewhere on the high-end of the spectrum (in terms of both fidelity and costs) ranging from Courseware to Part-task

devices to Cockpit Procedure Trainers to Full Mission Simulations to Distributed Mission Simulation to Live (Weapon) Training with non-EVS equipped aircraft, and eventually to Live-Virtual-Constructive training. But does EVS provide the appropriate learning environment in a training program for fighter pilots?

One important characteristic of multi-ship ET as a training medium is that it is suitable for team training, i.e. crew of all EVS-equipped aircraft that are connected via ET data-link, the flight lead and wingmen. This puts ET in the same league as DMT, LVC and live exercises with red air.

In terms of realism, the working hypothesis in fighter pilot training applications is that competencies only transfer from a situation that is identical or almost identical to the battle-field situation. This is a solid hypothesis in the absence of convincing counter-evidence. Moreover, with regard to these competencies, one should not rule out the possibility of negative transfer from training environments that depart considerably from full realism. With EVS one should distinguish between (1) the own-ship itself, which is real, (2) the degree of realism of the virtual world environment, i.e. the simulated battlefield conditions, and (3) the degree of realism of the own-ship sensor stimulation. Where ground-based simulation is challenged with achieving realism in all three domains, EVS is mainly concerned with creating realistic battlefield conditions, particularly realistically behaving Computer Generated Forces (CGFs). To exhibit realistic (intelligent and sense-making) behaviour, CGFs (either red or blue) need to be able to reason with knowledge, for example concerning the doctrine, battlefield intelligence, rules-of-engagement, (tactical) operating procedures, manoeuvres, platform capabilities, and etcetera. As is the case for ground-based simulation, the creation of realistic behaving CGFs is a grand challenge for EVS. In terms of EVS as a medium that is suitable for the provision of instruction, one may consider the following qualifications:

- Control over the training task by an instructor or scenario manager is obviously more complicated than with ground-based simulation, in which the Instructor Operating Station is an integral part of the simulator.

- EVS provides the opportunity for detailed and objective assessment of performance.

- The potential to vary the content, order, repetition and timing of training elements is higher that with the various forms of live training and exercises. However, it is yet an R&D challenge to develop an appropriate instructor interface.

- Similarly to LVC, EVS is particularly suited for training in a whole-task/ full mission context.

- Unlike other high-end training media, EVS is deployable to bare-base conditions.

- The high fidelity of the flight and mission environment reduces the risk for negative training. In the current capability simulation-induced sickness is fairly improbable.

- Currently, the possibilities for instructional techniques involving real-time extrinsic feedback (using guidance, cueing, or prompting) by an instructor are limited.

Considering the acquisition and life-cycle costs of training media, a cost driver of EVS will be the implementation on-board of the aircraft and this is preferably addressed in the design phase of the aircraft. Also, depending on the implementation, airworthiness certification has to be taken into account. However, when compared with other forms of training at the high-end of the spectrum, important cost-savings are apparent. The cost-savings relative to conventional live training, i.e. less "red air", less expensive EW ranges, etc. have already been mentioned. When compared to full mission simulation and distributed mission simulation, the aircraft motion, control loading, and aircraft flight data package are integral parts

of the aircraft, and no built infrastructure is needed for EVS. However, fuel and other aircraft life cycle costs must be added.

7.0 DISCUSSION POINTS

In the preceding sections, some use-aspects of EVS in multi-ship configuration were discussed. EVS as an enabler of ET potentially provides advantages from the National level to the end-user level, but to realise some of these advantages, challenges need to be encountered.

As with ground-based simulation, one may distinguish between low-fidelity EVS and high-fidelity EVS, just like some low-fidelity ground-based flight training devices are suitable for instrument training only, while other training devices provide full-mission capability. Although ET implies a high fidelity flight environment, a hypothetical single-ship EVS implementation may only be suitable to simulate SAM threats, which would mean that other elements of mission training have to be provided in the conventional way. This illustrates that there will be tasks and training objectives for training of which current EVS can only offer a partial solution. The description of the air-to-air engagement in the previous section showed that visual tasks, such as visual detection and identification of targets, requires solutions that are not yet available in current EVS designs.

Since the overall objective of EVS on fighter aircraft is to provide *mission training* at the later stages of initial training, during continuation training or for mission rehearsal, the positive training (transfer) would depend on the actual capabilities of the EVS, including CGFs, instruction aids, scenario management and usability features at the squadron level, and the other available training methods and equipment. In any case, the position of ET in the training program, like any other training medium, should optimise the learning curve towards the required mission competencies. This requires an analysis of training objectives to which it could contribute, given the full range of operational tasks.

In summary, from a training and simulation view, we see the main R&D challenges for EVS and ET as the following:

- Truly intelligent CGFs that exhibit convincing blue or red behaviour, integrated in a C4ISR simulation model in a joint environment;

- Visualization of WVR targets (e.g. by projection on a Helmet Mounted Display, possibly using symbology);

- Real-time interface between EVS and instructor or scenario manager for scenario manipulation and other instructional interventions;

- Use aspects of ET at different organisational levels to ensure sustained embedding in the Defence organisation;

- Development of a link between ET mission evaluation and competency based training program.

8.0 ACKNOWLEDGEMENTS

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